

Virtual Design of Stirling Engine Combustion Chamber

Z. Kaplan, P. Novotný, and V. Přístěk

Brno University of Technology, Faculty of Mechanical Engineering,
Institute of Automotive Engineering, Technická 2896/2, Brno, Czech Republic
kaplan@fme.vutbr.cz

Abstract. The paper deals with the designing of a combustion chamber of the Stirling engine using the CFD approach. Virtual prototypes enabled to optimize the parameters in the combustion chamber, to increase efficiency of the energy conversion, and to decrease emissions. The presented results help to increase the Stirling engine efficiency together with a significant time decrease of development process.

1 Introduction

Efficient utilisation of biomass for energy can be achieved with a minimum of environmental impact if biomass is used for small-scale combined heat and power (CHP) production in smaller towns and villages close to biomass production sites as well as in the wood processing industries. In the range of an electric power output up to 100 kW_{el} Stirling engines are presently the only useful technology for CHP generation based on solid bio-fuels which has the potential to meet the technical end economical demands in an environmental way [1].

Stirling engines for CHP plants using gas as fuel have been developed for more than five years at the Brno University of Technology, Institute of Automotive Engineering. As a part of these activities a 500 W pilot Stirling engine was build. The pilot engine development has been supported by advanced computational modelling.

Requirements for computational modelling of different physical phenomena rise in the present time. Dynamics of Stirling engine components or dynamics of fluid processes of external heat supply engines are specific which is given by the fact that the course of observed values (force, temperature, pressure, heat transfer, etc.) is periodical [3].

Modern computational models like Multi-body System (MBS), Finite Element Method (FEM) or Computational Fluid Dynamics (CFD) deliver relatively accurate results but only if correct inputs are included. This represents a fundamental drawback of modern computational methods. The correct inputs can be greatly obtained from measurements, therefore, the measurements are continuously a fundamental part of the Stirling engine development.

The development of a Stirling engine starts with an initial design of thermodynamic engine parameters. These proposals significantly affect engine geometry (engine displacement, working medium etc). However, there are still many restrictions, one of the strictest ones is the economical aspect and this has to be carefully considered.

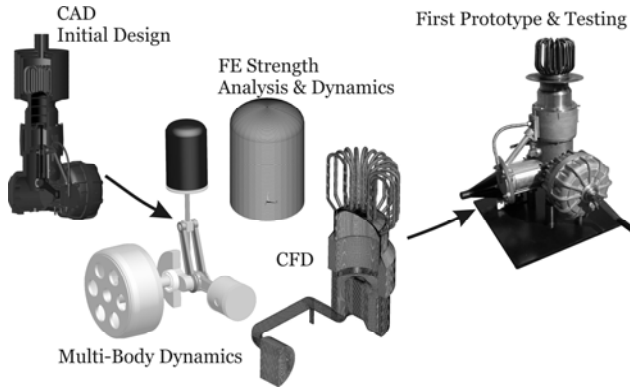


Fig. 1. CAE models and first prototype of Stirling Engine

After the main engine parameters are proposed the accent is changed to advanced CAE (Computer Aided Engineering) computational models. CAE models of the Stirling engine are presented in Figure 1. Stirling engine geometry is set to an initial cranktrain position for the start of all simulations. If flow processes are to be studied, a volume of a working medium (for CFD calculations) has to be created by a subtraction of a Stirling engine CAD model from a properly chosen volume. The design phase finishes with a real prototype of the Stirling engine. The real prototype engine also enables to validate CAE calculation results.

2 Stirling Engine Combustion Chamber

The main objective of the Stirling combustion chamber development is to ensure a uniform heat transfer to the heater tubes, beside a reduction of the internal manifold volume, and to adapt the geometry of the Stirling heater in order to allow an efficient implementation of components like a burner or an intake manifold. The CAD model of resultant version of Stirling engine combustion chamber is presented in Figure 2.

The Stirling heat exchanger includes 24 u-shaped tubes connected to the cylinder side. The burner is positioned in a combustion chamber axis and can be axially moved. The intake manifold is placed tangentially to a outer cover of the combustion chamber and enables efficient air warm-up.

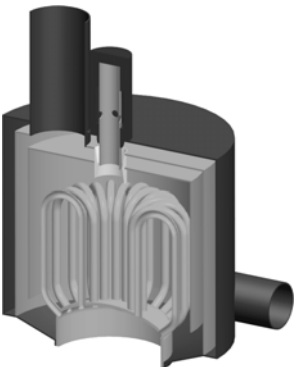


Fig. 2. CAD model of Stirling combustion chamber

3 Design of Combustion Chamber Volume

During the development phase a number of versions of air intake manifolds have been investigated. The experiences as well as CFD results confirmed the tangential position of the intake manifold.

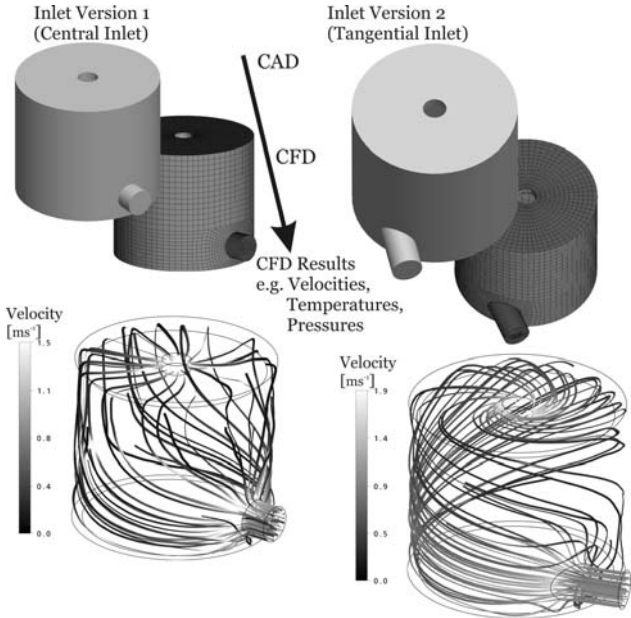


Fig. 3. Combustion chamber outer volume design versions and results

Figure 3 shows the CFD computational model and result examples of two versions - intake manifold located centrally and tangentially to the combustion chamber outer cover. The tangentially placed intake manifold reduces flow losses and enables a better warm-up of air compared to the centrally placed intake manifold.

4 Burner Position Solution

The proposed pilot Stirling engine fuel is gas supported from a gas-bottle. Gas enters the combustion chamber thru a nozzle and a burner. Air and gas mixture burns and resultant heat is distributed to the heat exchanger pipes.

A burner position can be axially changed to achieve the optimal combustion process. First burner designs showed large non-uniform temperature distribution on the heat exchanger pipes. After a few design modification the final design has been proposed and suitable temperature distributions have been achieved. The axial position of the burner pipe can be easily adjusted for the best working conditions. Figure 4 presents details of three burner pipe positions and results (pressures and velocities) on section plane for the final burner design.

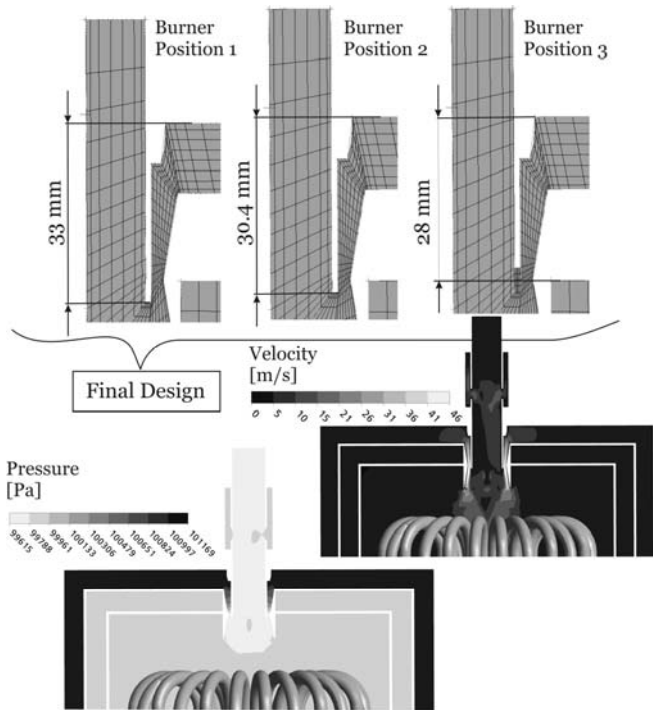


Fig. 4. Burner position description and results

5 Complete Combustion Chamber Solution

The combustion chamber is mainly made from 2 mm steel plates connected by welding technology. The combustion chamber design can be characterized as a low cost because this is one of the current Stirling engine design objectives. Therefore, all the shapes (channels, pipes etc.) are not ideally designed for fluent flow.

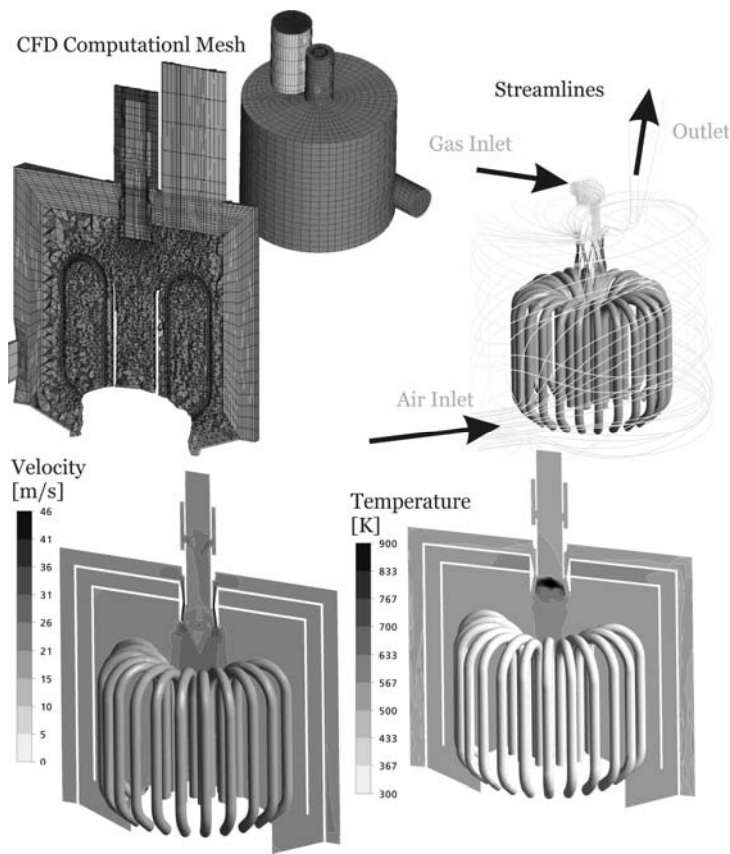


Fig. 5. Combustion chamber model and results

The complete combustion chamber is modelled by using CFD as well. The computational hybrid mesh includes hexa and tetra cells with defined boundary layers. Figure 5 shows the computational model and examples of results like flow streamlines or velocities and pressures in cut plane. The results are presented only for the final design of the combustion chamber.

6 Conclusion

The combustion chamber of the Stirling engine with electric power output 500W has been successfully resolved and the experience enable to produce a new combustion chamber for more powerful Stirling engines prepared by our team of researchers. Computational models of thermodynamic processes in the combustion chamber and in the Stirling engine respectively have been created as higher-level computational models based on CFD models of physical processes occurring in real units, using only the minimum simplifying assumptions. Developed and successfully verified computational models will be greatly used before the future, more powerful Stirling engine is made. All performed technical experiments will also offer advances in the future. Computational models and technical experiments will speed up the development of Stirling engines with better technical and economic parameters.

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References

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